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EXPLOSION OF AVIATION KEROSENE (JET A) VAPORS

(22 pages)

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Explosion of Aviation Kerosene (Jet A) Vapors

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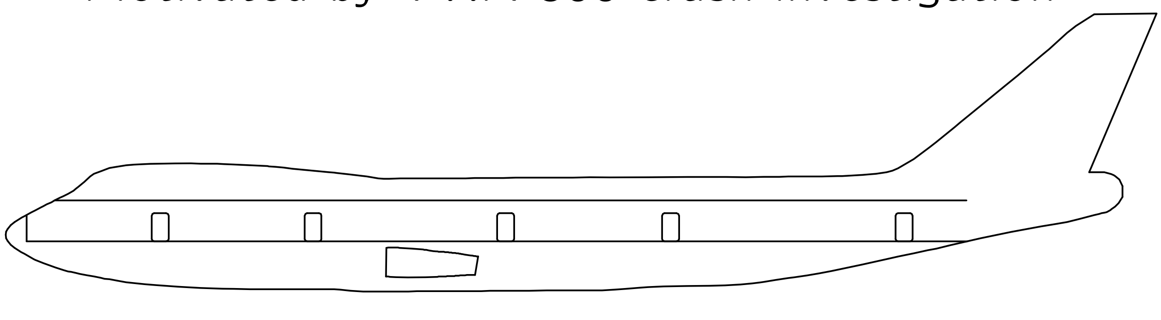
October 7, 1997

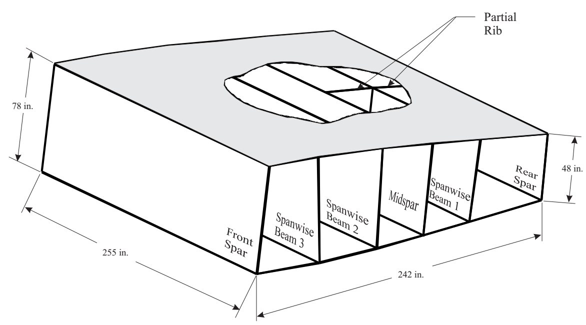
Sponsored by the
National Transportation Safety Board
under Order NTSB12-97-SP-0127

Caltech Research Program

- Motivated by TWA 800 crash investigation



- Present Jet A data base inadequate
- Issues:
  - Chemical composition of fuel vapors vs liquid
    - Effect of temperature (T)
    - Effect of fuel amount (M/V)
  - How does flammability depend on ignition energy?
  - Laminar and turbulent flame speeds?
  - Combustion within multi-compartment, vented tanks?



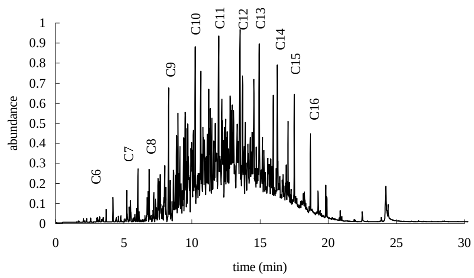
Scope of Presentation

$\boxed{\text{Results of basic studies on Jet A}}$

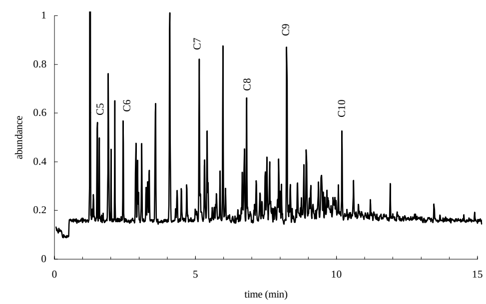
- Chemical composition
- vapor pressure
- Ignition energy and flammability
- Flame speed
- Explosion development

Chemical Composition I.

- Kerosene is a mixture of many species,



Liquid



Vapor (40°C, 300 kg/m^3)

Gas-Chromatograph Mass Spectrometer studies at CIT.

- Chemical composition is the key to understanding combustion

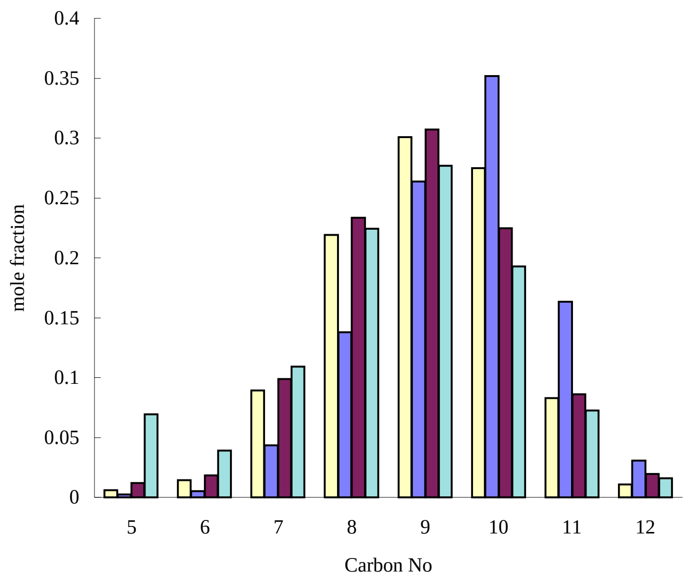
- New Studies needed for quantification

  – C1-C8 equivalance, headspace GC at University of Nevada, Reno (Woodrow)

  – Detailed speciation at Desert Research Insitute, Reno (Sagebiel)

Vapor and liquid composition are very different, depend on both temperature and mass loading.

Chemical Composition II



Results of UNR/DRI studies

- Mean molar mass of vapor 120 to 140 depends on fuel origin, handling & weathering
- H/C ratio of 1.8 in vapor
- Over 160 species in vapor, up to C=12.
- Depletion of light ends observed for small mass loading
- Light ends enhanced at higher temperatures

Significance of Vapor Pressure P_σ

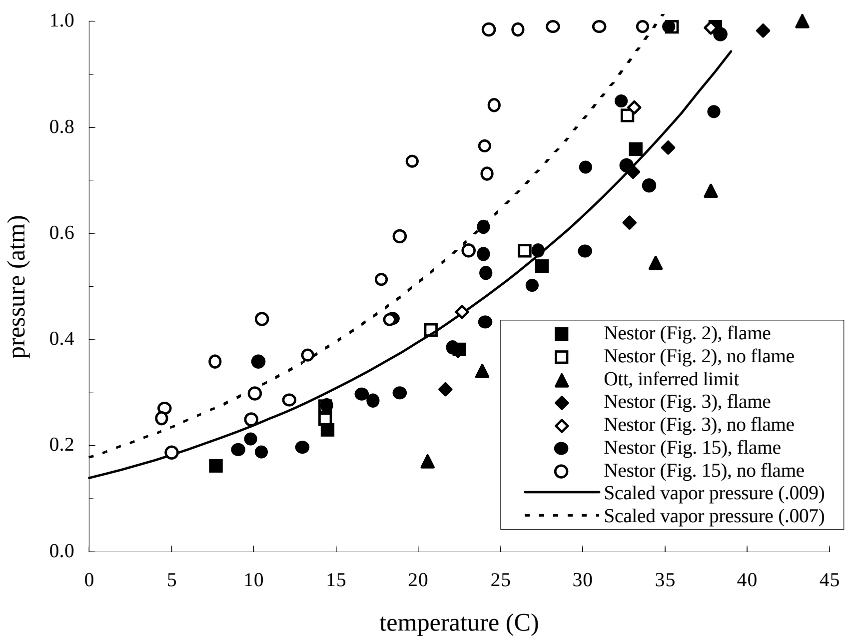
- Liquid evaporation creates flammable vapor-air mixtures

- P_σ determines fuel-air mixture fraction

$$\text{mole:} \quad X = \frac{P_\sigma(T_{fuel})}{P_{air}} \quad \text{mass:} \quad f = \frac{P_\sigma(T_{fuel})}{P_{air}}\frac{W_{fuel}}{W_{air}}$$

- Flammability limits

$$f > f_{LFL} \sim 0.035 \qquad \text{or} \qquad X > X_{LFL} \sim 0.7 - 0.8\%$$



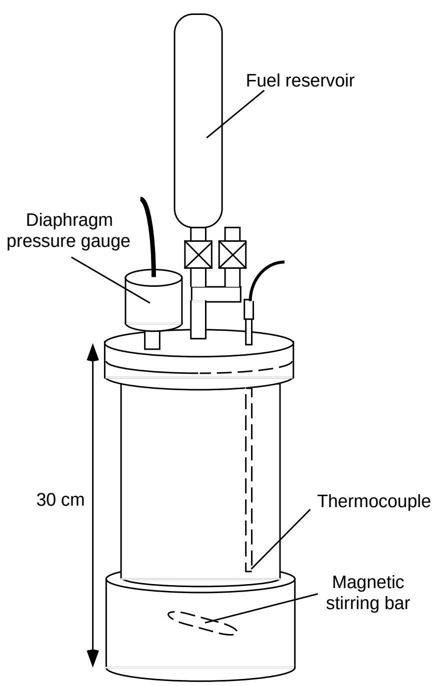
- Determines peak pressure caused by combustion

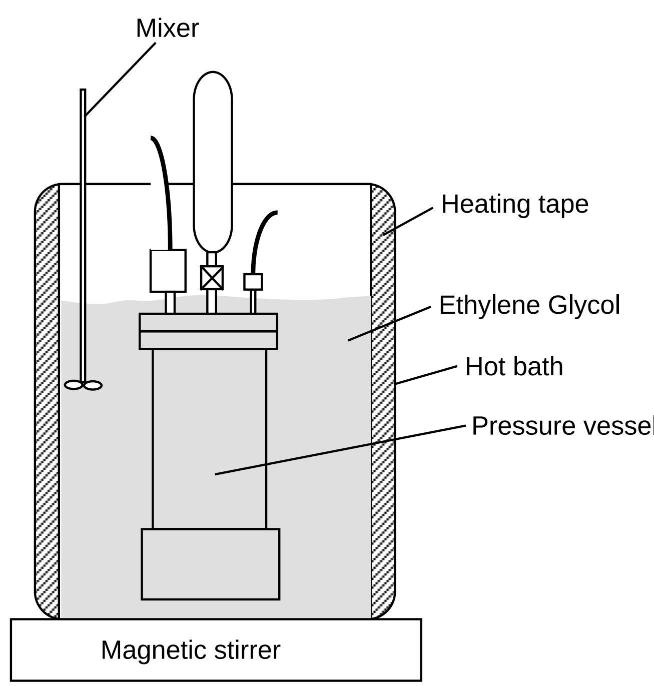
$$\Delta P_{max} = \frac{W_{fuel}}{W_{air}}\frac{q}{c_v T_1}P_\sigma(T_{fuel})$$

Vapor Pressure Measurements

Issues:

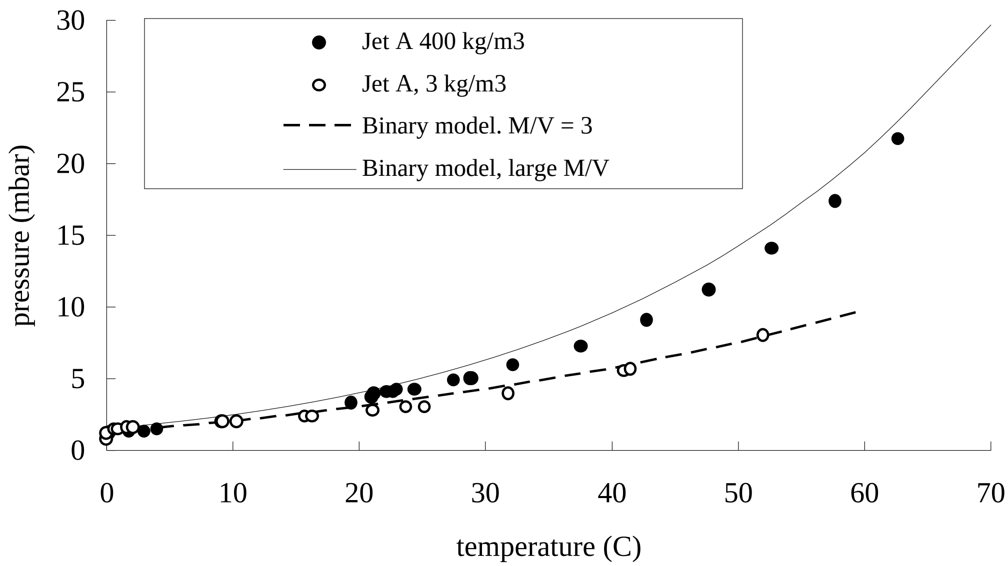
- dissolved air. (degassing)
- multicomponent (stirring)
- batch dependent
- Reid method inadequate
- existing correlations unreliable
- New measurements needed



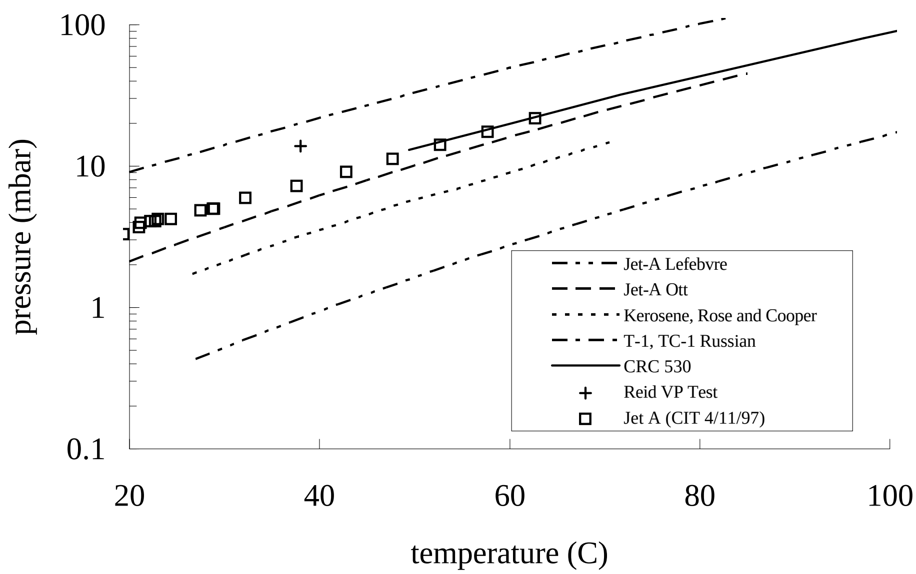


Vapor Pressure Results

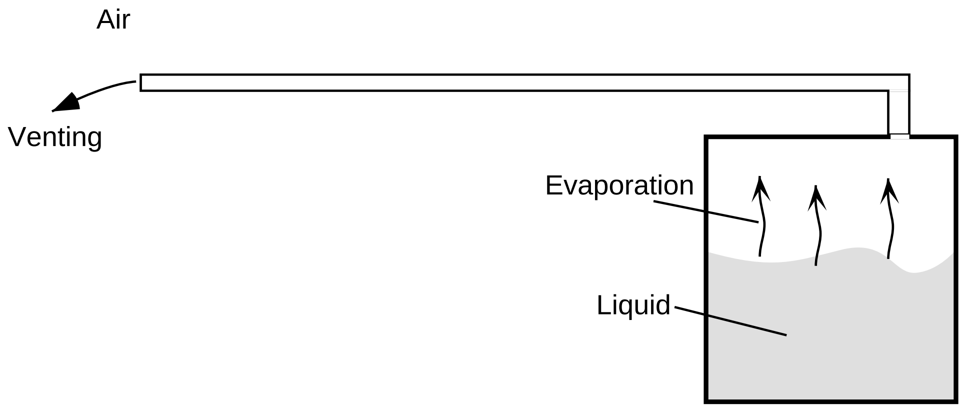
Raw data, simple mixture model:



Comparison with published "data":



Multicomponent Mixture



Issues:

- wide range of $\mathrm{C}_n\mathrm{H}_m$ in Jet A
- preferential evaporation of "light ends"
- dependence of P_σ, composition on M/V

Simple model:

- use 8 components from UNR measurements
  - mixture vapor pressure
  $$P_\sigma = \sum x_i \gamma_i P_{\sigma,i}$$
  - activity coefficients γ_i estimated ≈ 1.
- Requires validation

Flammability and Explosion

- Flammability depends on many factors
  - Ignition source (energy, temperature)
  - Fuel state (vapor vs mist, mass loading)
  - Turbulence
  - Temperature
  - Pressure

  Standard approaches:

- Flash point test (ASTM D56) Jet A: 40 to 60 °C LAX Jet A, 46 to 48°C

  10 to 15 °C above explosion limits. Not representative of actual explosion behavior.

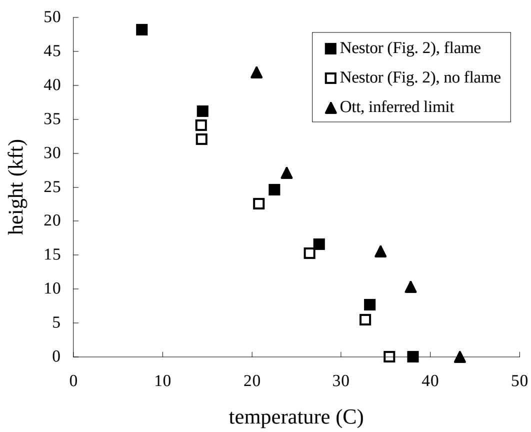
- Vessel studies.

  Previous work used fixed energy (16-25 J), large mass loading (100 to 120 kg/m^3)

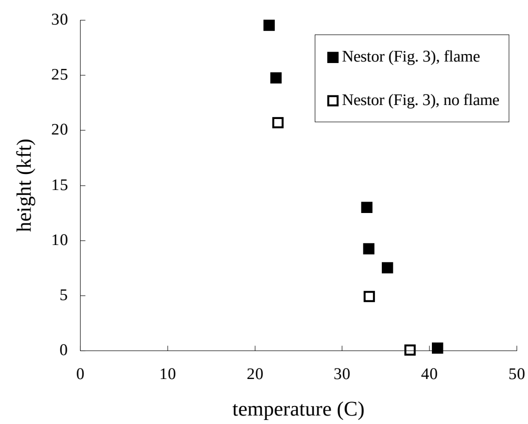
  Not representative of many ignition sources, and empty fuel tank conditions.

Previous Studies on Flammability

- L. J. Nestor 1967 "Investigation of Turbine...", Report DS-67-7, Naval Air Propulsion Test Center.
- E. E. Ott 1970 "Effects of Fuel Slosh..." AFAPL-TR-70-65.
- T. C. Kosvic et al. 1971 "Analysis of Aircraft Fuel...", AFAPL-TR-71-7.



(a)



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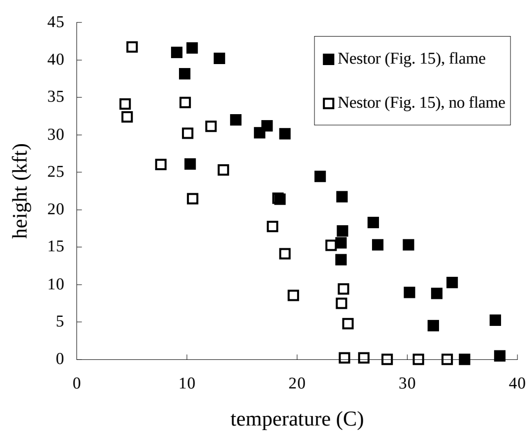
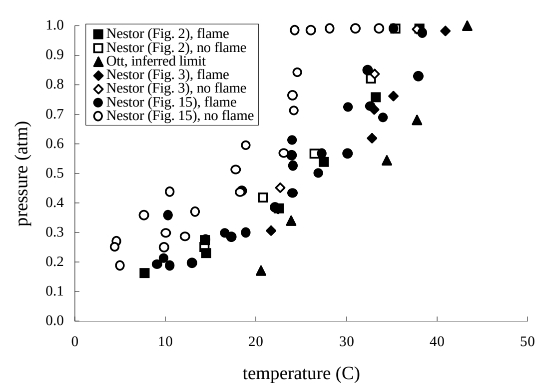


(c)



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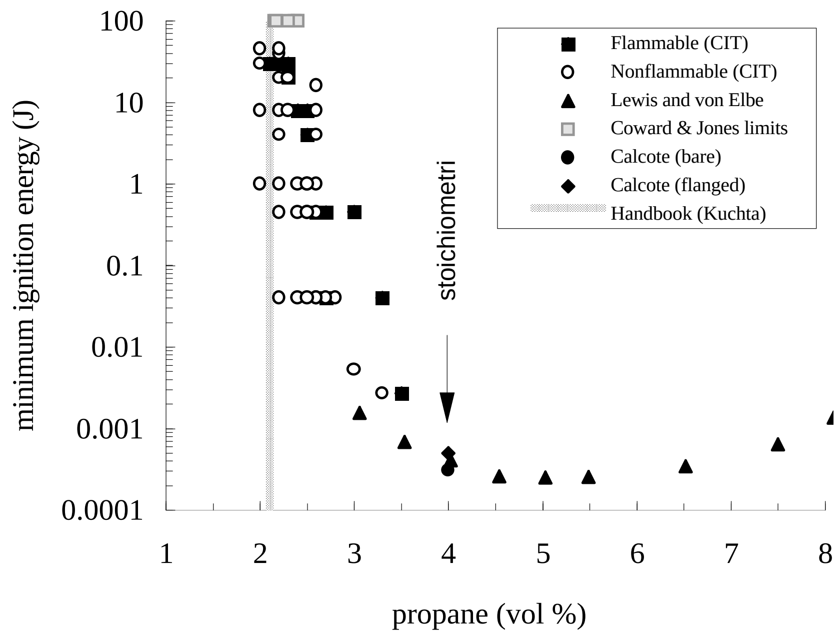
Ignition Energy



Propane-Air mixtures, 300 K, 1 bar

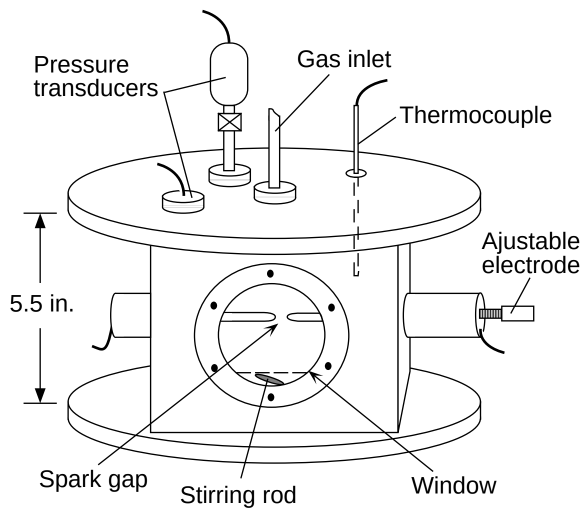
- Minimum of 0.25 mJ occurs for rich mixtures
- Strong dependence on concentration
- Ignition energy very high (100 J) near LFL
- Not previously measured for JET A vapor
- thermal sources require separate consideration

CIT Ignition Testing

Emphasizes:

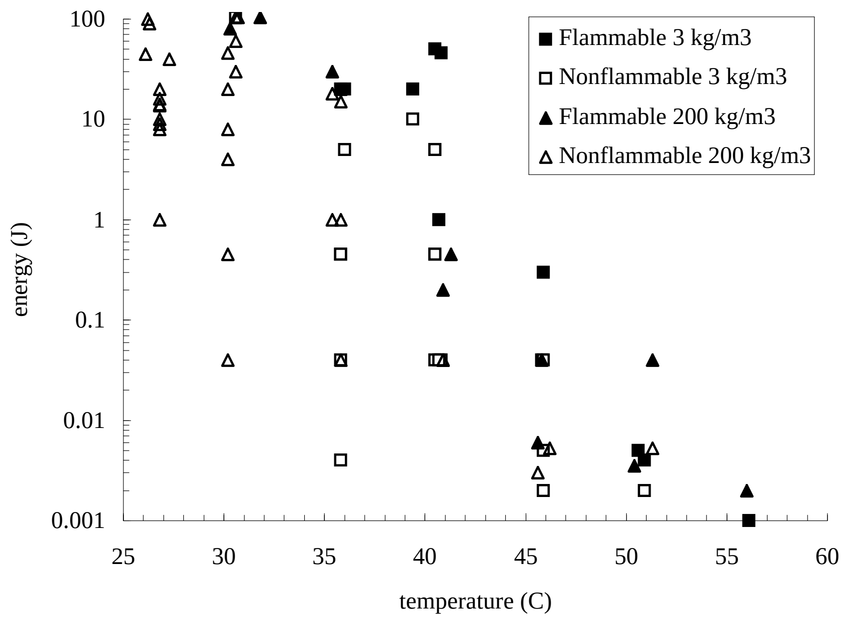
- fuel mass loading M/V
- spray injection vs stagnant pools
- ignition energy
- jet ignition vs sparks

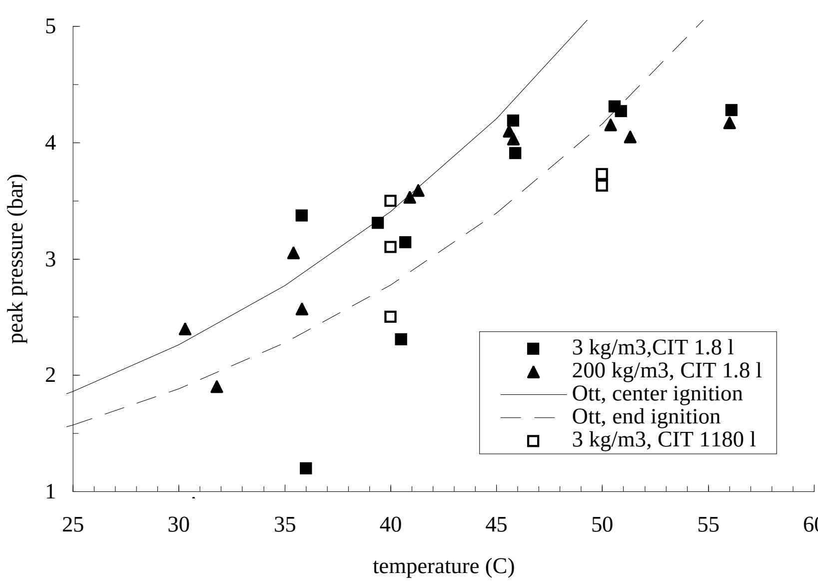
Ignition vessel:



- 1.84 liter volume
- video schlieren
- spark ignition source
- $P(t)$, $T(t)$
  - 1 mJ to 100 J
  - 3.3 mm gap

Jet A Flammability

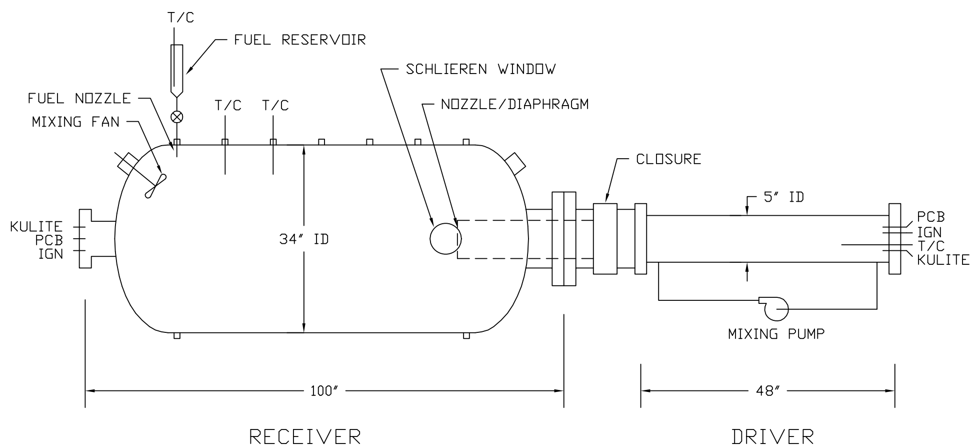


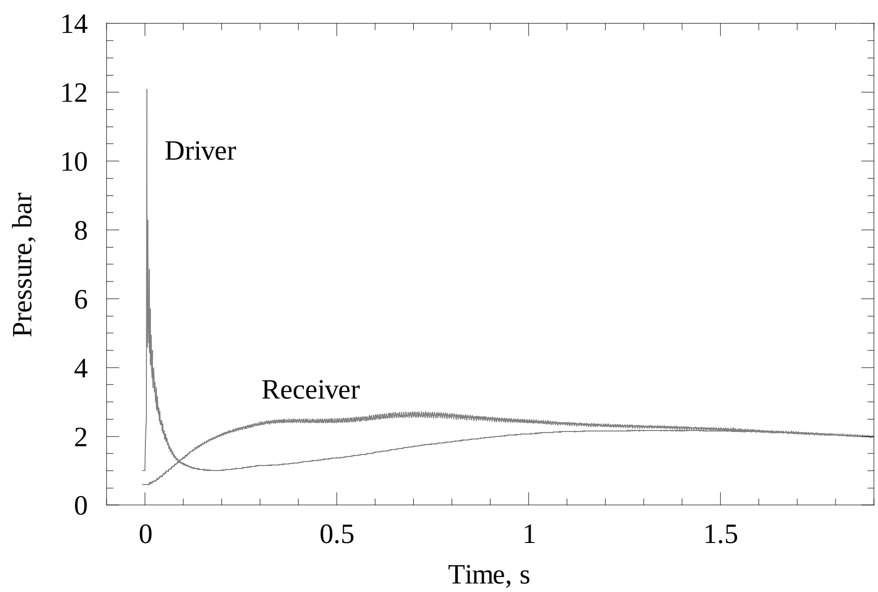


Explosion Development

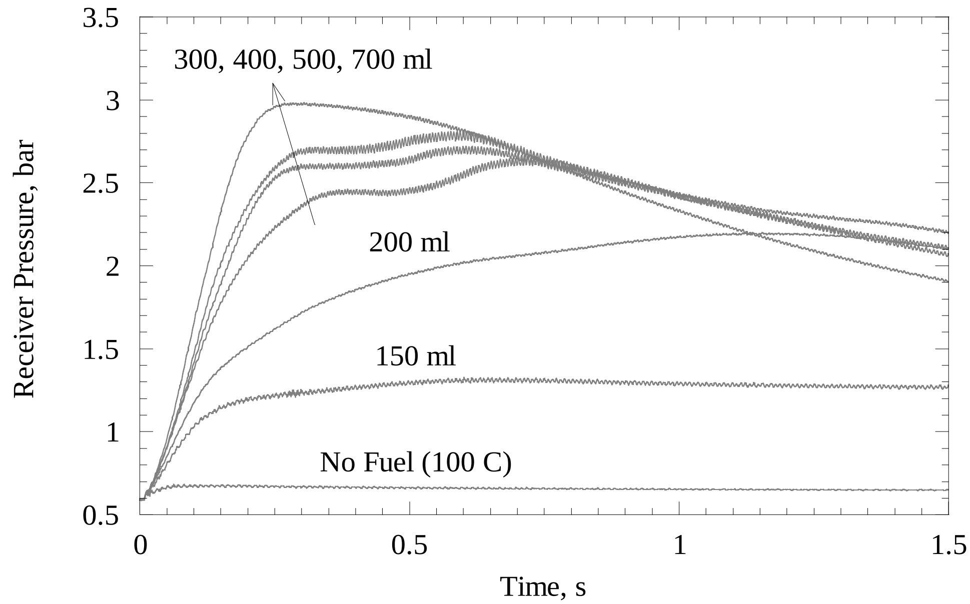
- Issues
  - peak pressure
  - burn time
  - flame speed
  - quenching behavior
  - turbulent flame speed
  - multi-compartment burns
- Parameters:
  - mass loading M/V
  - fuel temperature T
  - ambient pressure P
  - ignition source, fans, partitiions, etc.

HYJET Facility

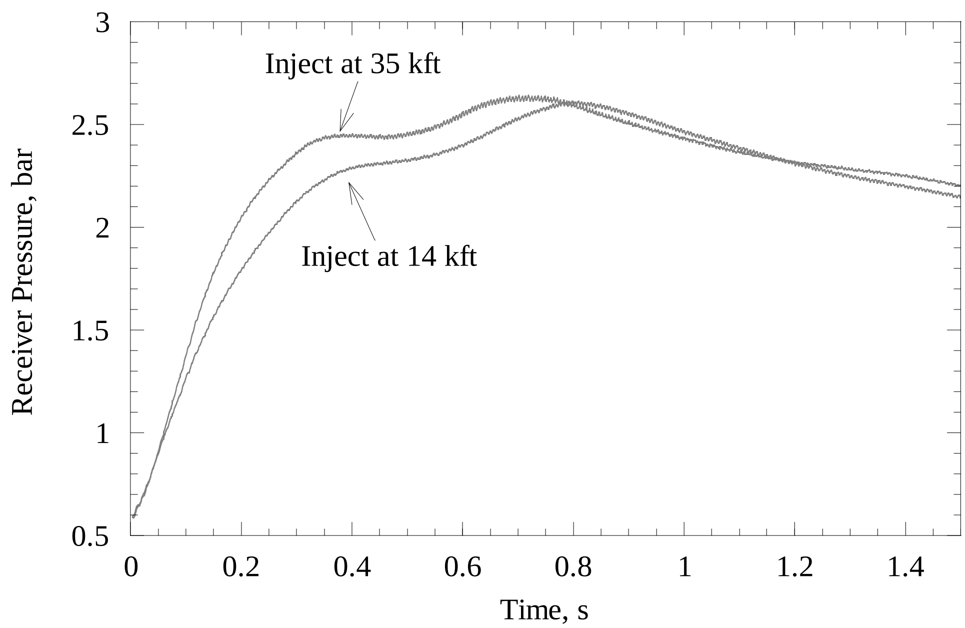




Jet A, 40°C I.

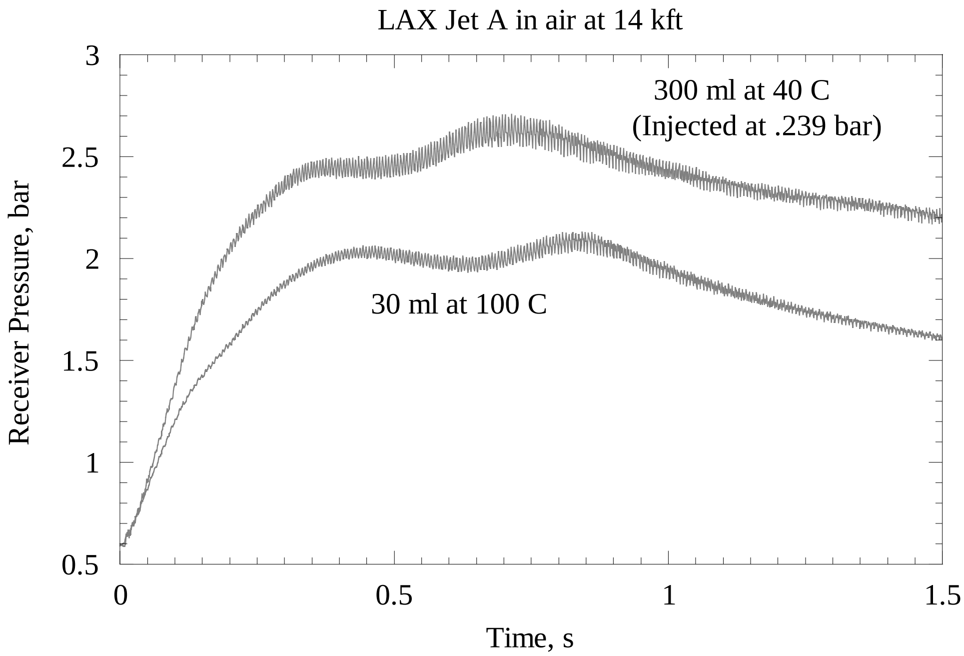


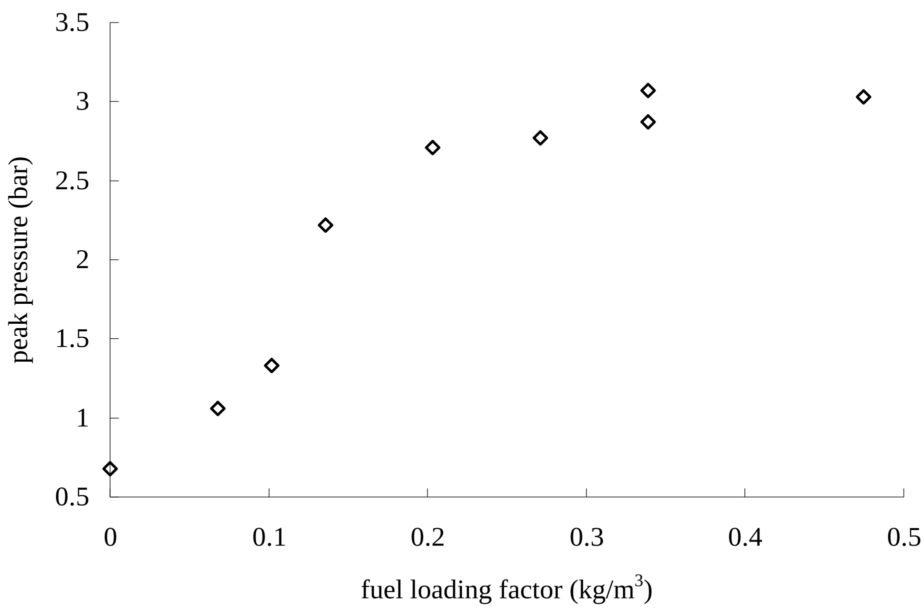
Receiver Pressure, bar
Time, s
300, 400, 500, 700 ml
200 ml
150 ml
No Fuel (100 C)



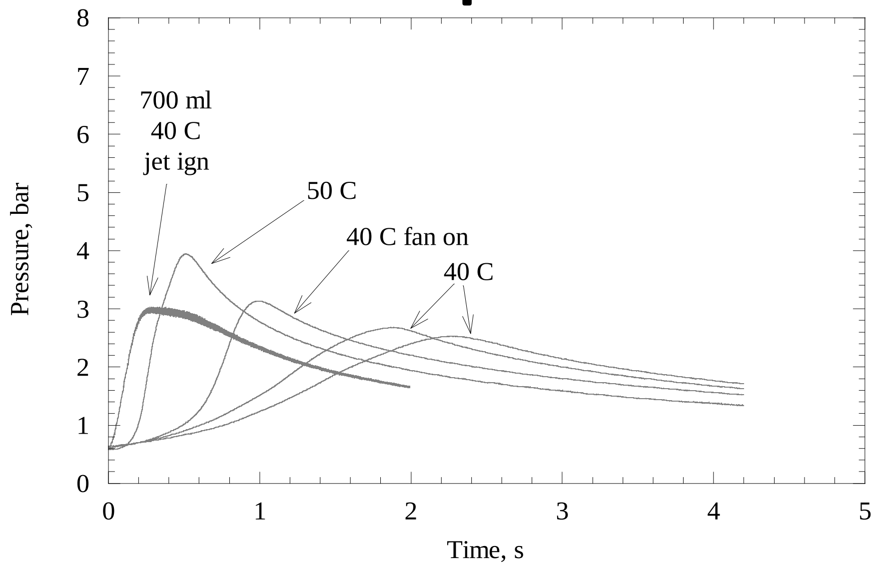
Receiver Pressure, bar
Time, s
Inject at 35 kft
Inject at 14 kft

Jet A, 40°C II.


LAX Jet A in air at 14 kft
300 ml at 40 C
(Injected at .239 bar)
30 ml at 100 C
Receiver Pressure, bar
Time, s
3
2.5
2
1.5
1
0.5
0
0.5
1
1.5


peak pressure (bar)
fuel loading factor (kg/m^3)
3.5
3
2.5
2
1.5
1
0.5
0
0.1
0.2
0.3
0.4
0.5

Jet A Explosions



- Effect of fuel loading and state
- 1180 liter vessel
- Stagnant puddle of fuel (1 gal) in 4 cases
- fan on in one case
- spray injection in one case

Summary I.

- vapor composition very different than bulk liquid
- vapor pressure alone not useful without vapor composition
- multicomponent fuels do not have unique vapor pressure
- mass loading M/V affects composition
- flash point is not a useful characterization of explosion hazard

Summary II.

- MIE a strong function of composition
- .25 mJ not characteristic of near limit fuels
- MIE of Jet A is 100 J at 35°C
- MIE of Jet A is < 1 mJ at 55°C
- mass loading M/V effect mild for MIE and peak pressure
- $\Delta P_{max} = 4$ bar at 40 to 55°C ($P_\circ = .585$ bar) for $M/V \geq 3$ kg/m^3

Acknowledgements

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- Julian Lee (CIT)
- Chris Krok (CIT)
- Jim Woodrow (UNR)
- John Sagebiel (DRI)